ESIP Winter Meeting: Energy Cluster

NOAA/ GFDL Climate Modeling:

Global-to-regional Climate Information

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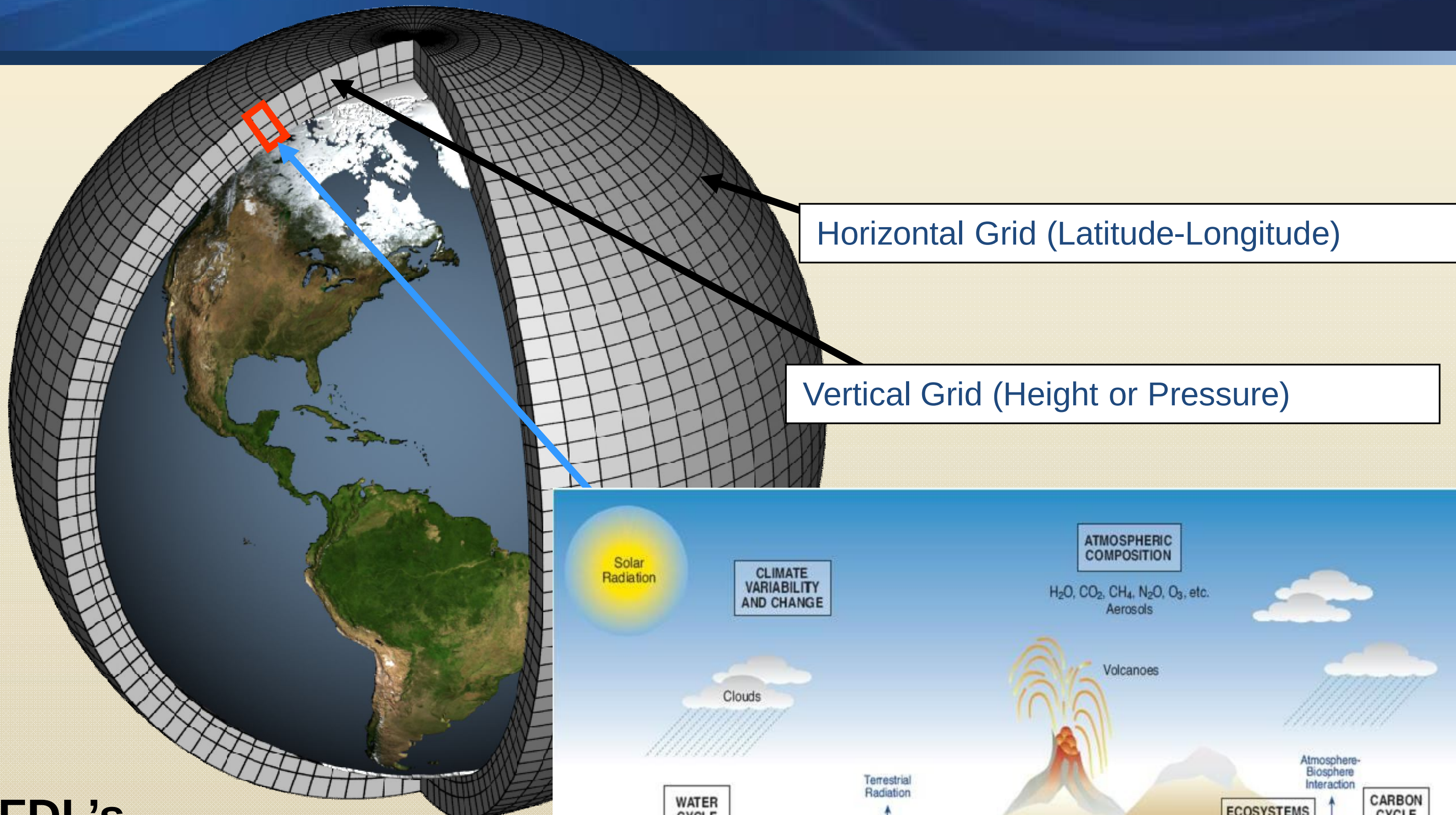
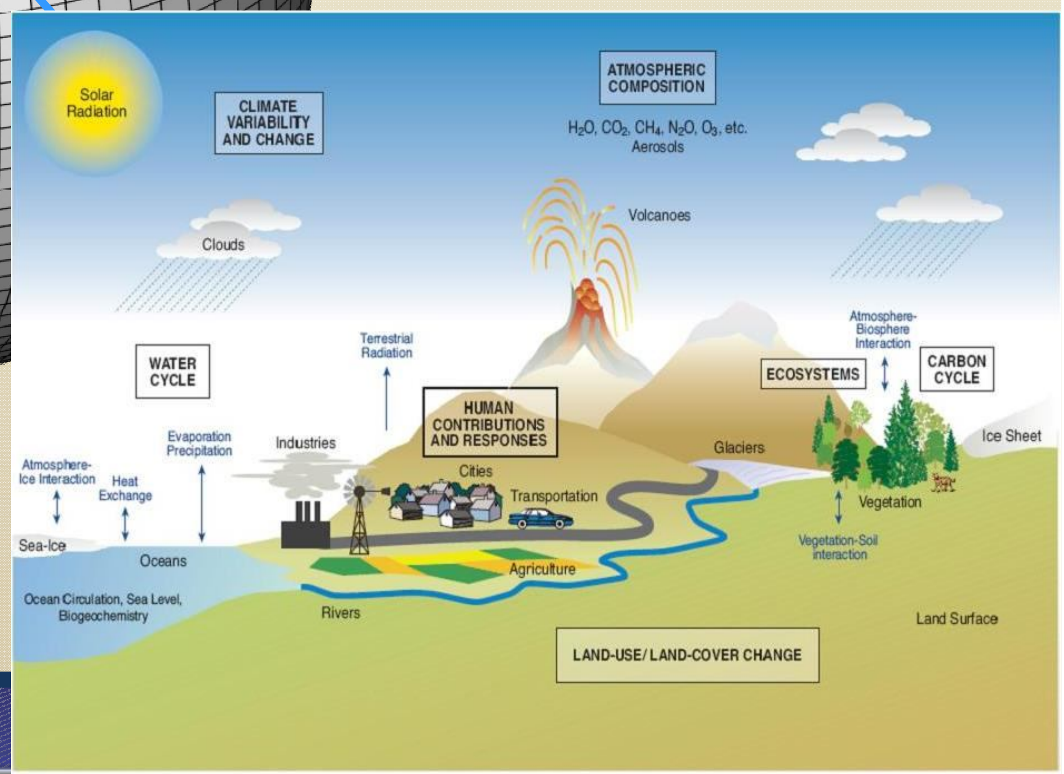
Schematic Global Climate Model





NOAA/ GFDL's CLIMATE and EARTH SYSTEM MODELING

Scientific challenges

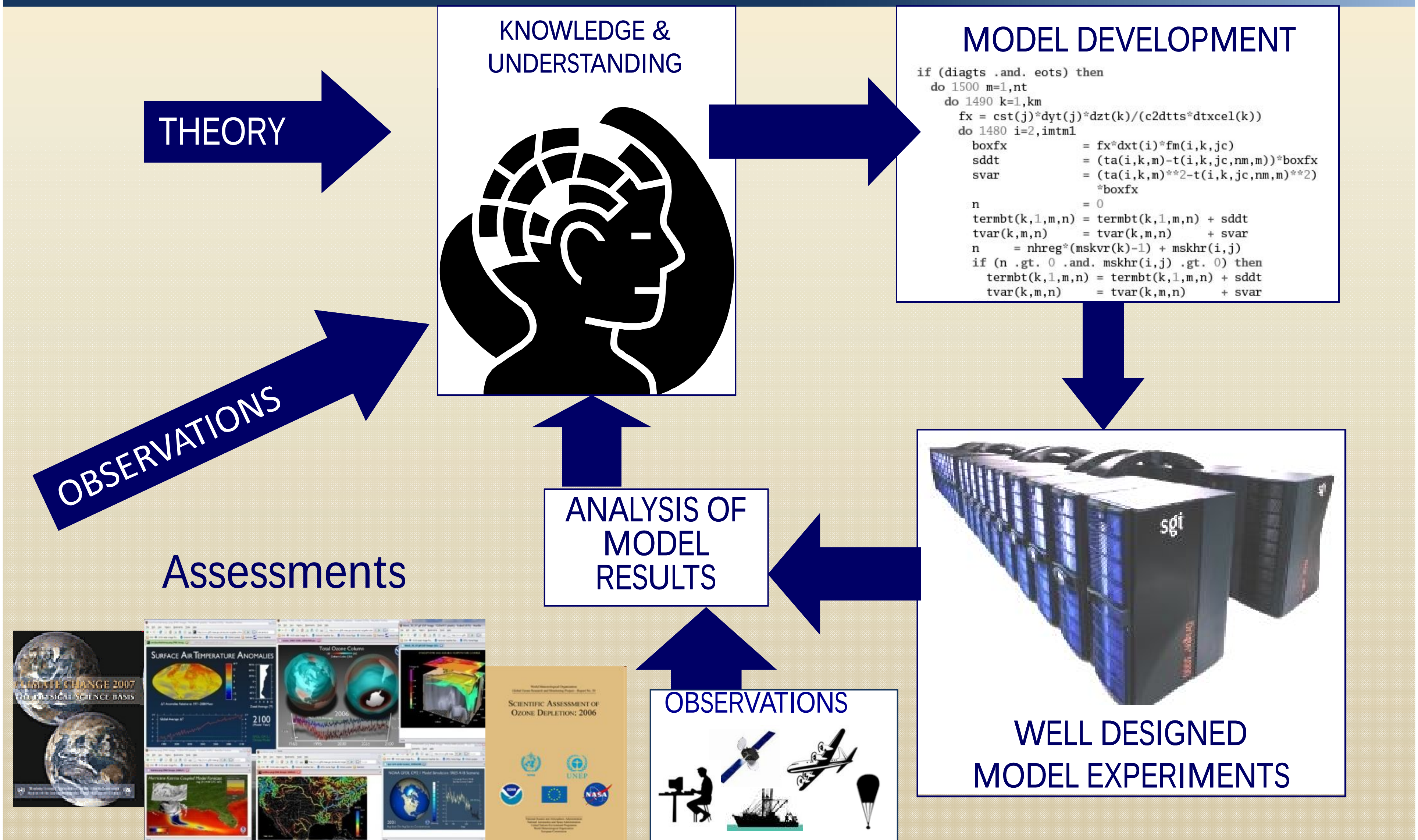
- Capturing the *Climate and the Earth System* (i.e., physics, dynamics, chemistry, biogeochemical cycles, ecology) with rigor and high-resolution

  - Advancements in the understanding of the processes and interactions

  - Increasing the realism of the complex "System" in model simulations

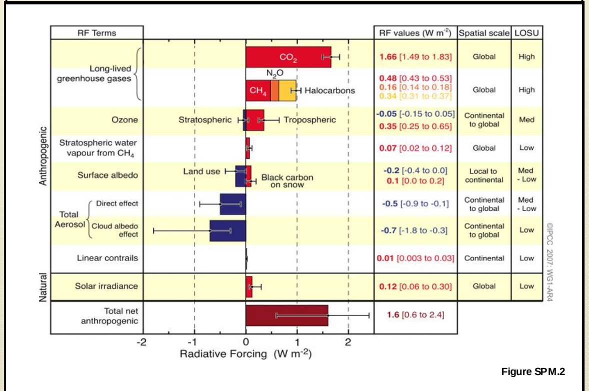
- Model verification against observations, intercomparisons, and synthesis.
- Time-scales (weeks to century-scale)
- Accurate predictions including the regional aspects
- Initial-value AND the Boundary-value nature of the problem (viz., "Forcing" of the system, initialization, assimilation, reanalysis)
- Characterization, quantification and resolution of uncertainties
- Increased ensemble members in model integrations for studies of extremes.
- Meeting timelines (e.g., Assessments, transition of well-vetted science to routine operations, multi-model ensemble analyses)

Planning, Execution, Results, Lessons

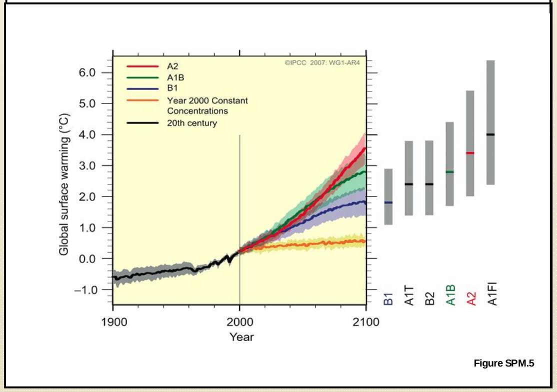


NOAA/OAR/GFDL Model Simulations

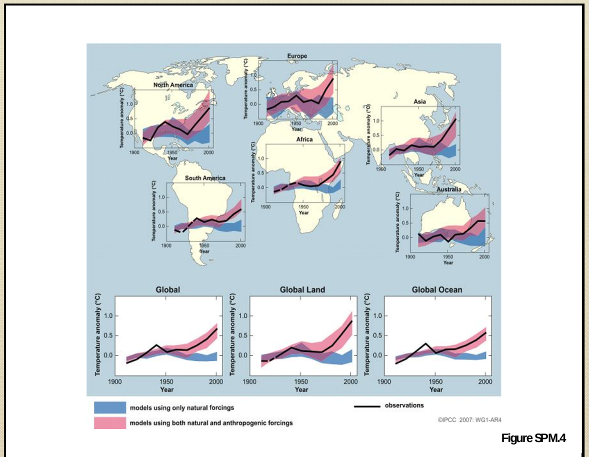
Anthro. RF > 0 (v. high conf.)



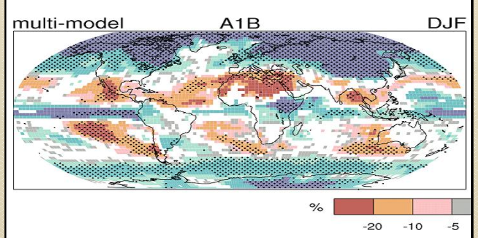
Projected global warming



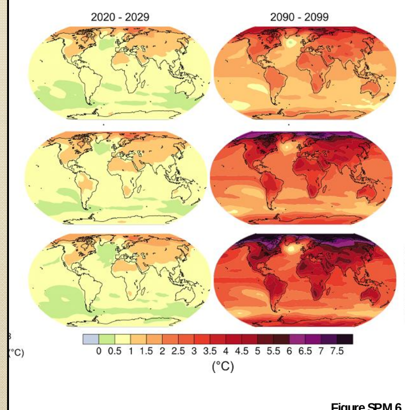
NOAA/ GFDL model simulations contributed to 5 of the key IPCC AR4 SPM conclusions



20th Cent. continental warming likely due to human activity

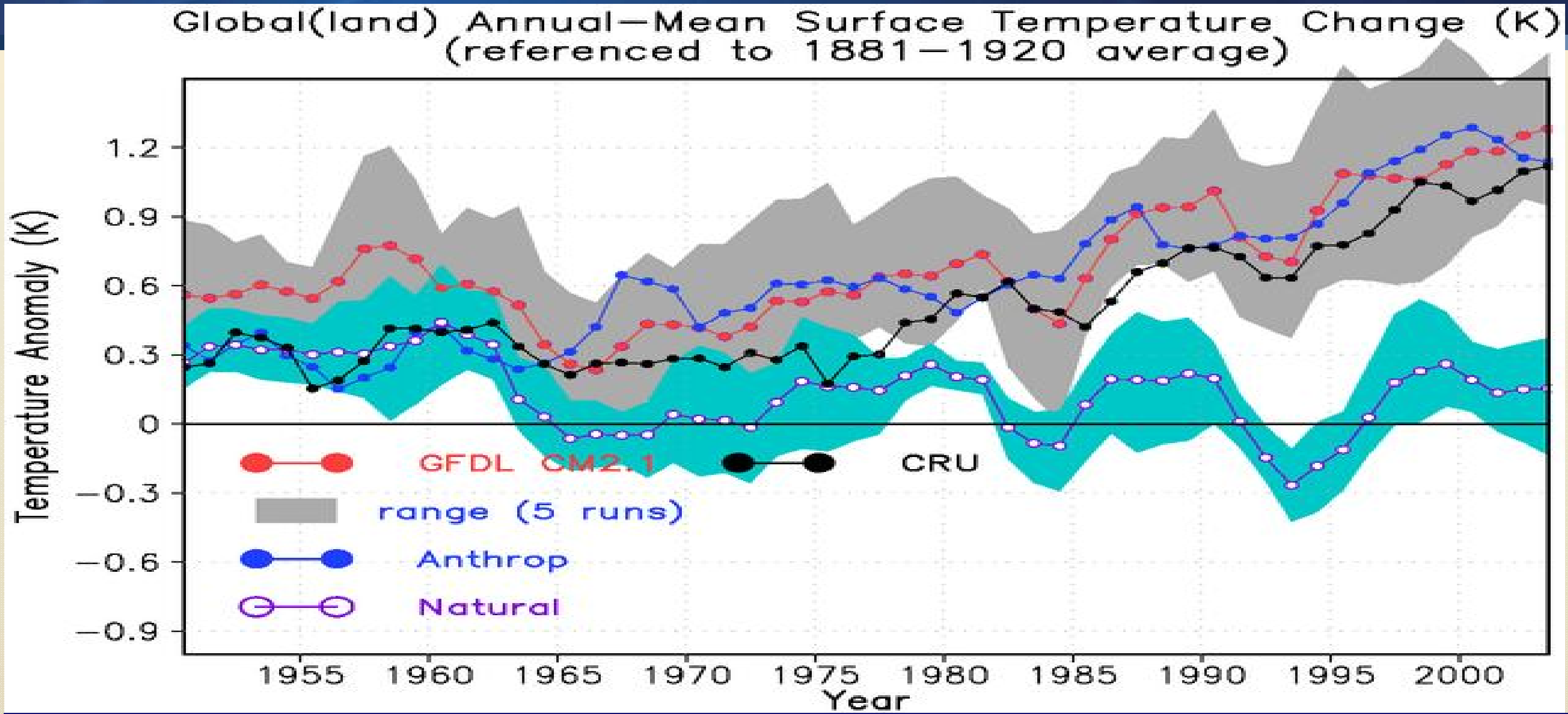


Projected pattern of rainfall changes in 21st Century



Proj. warming pattern in early and late 21st Cent.

RECENT HIGHLIGHTS [IPCC AR4 Simulations]
Attribution to CO2, Other GREENHOUSE GASES and AEROSOLS



<u>20th Century Global-mean Surface Temperature change</u>

<u>Total Anthropogenic → 0.8K</u>

<u>All Gases → 0.9K</u>; CO2 only → 0.5K

Anthro. Aerosols → - 0.2K

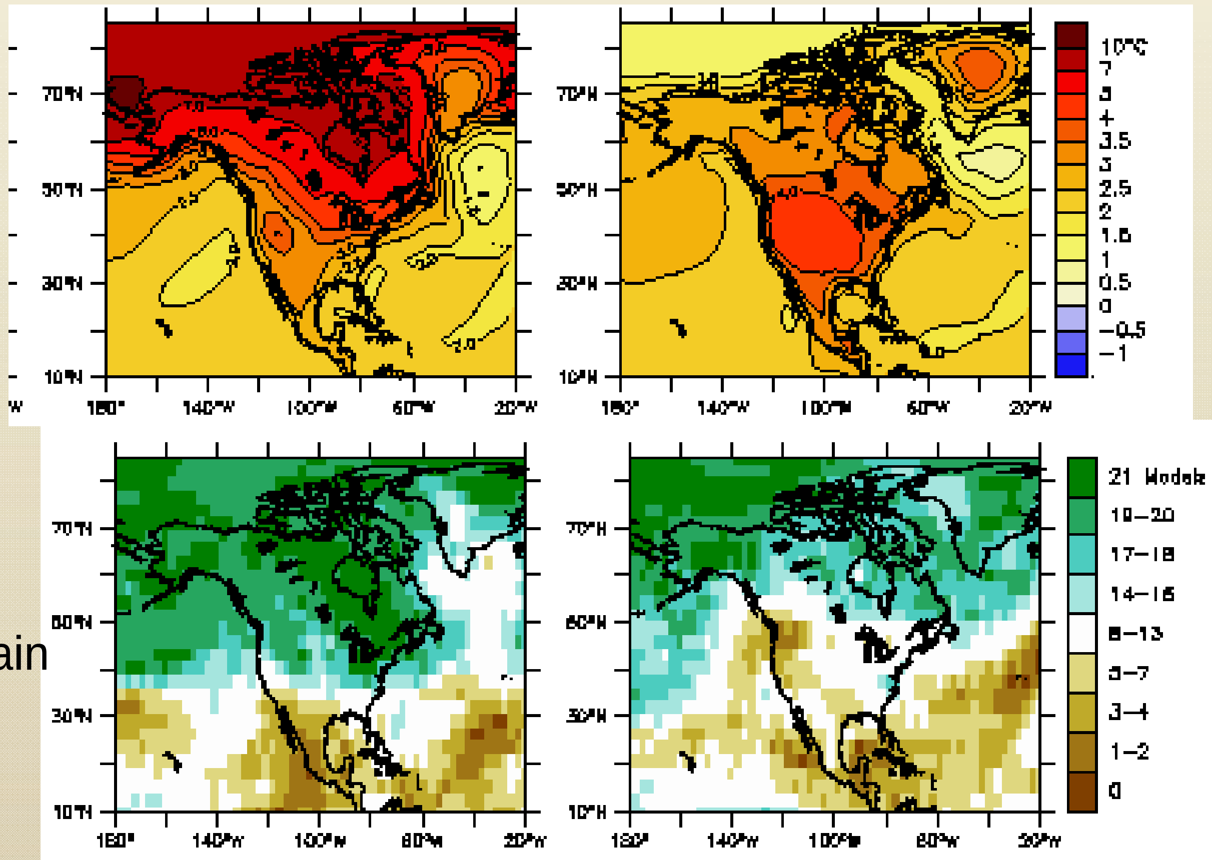
(BC+OC) → 0.2K; (Sulfate) → - 0.4K

Projected changes in temperature and precipitation in 21st century
A1B emission scenario; averaged over ~20 models with spatial resolutions of **~ 200km**

Winter | Summer

Warming everywhere

Green => wetter
Brown=> drier
White => uncertain



Winter: wetter in Northeast – drier in Southwest –
Summer: Drying extends northward, with larger uncertainty

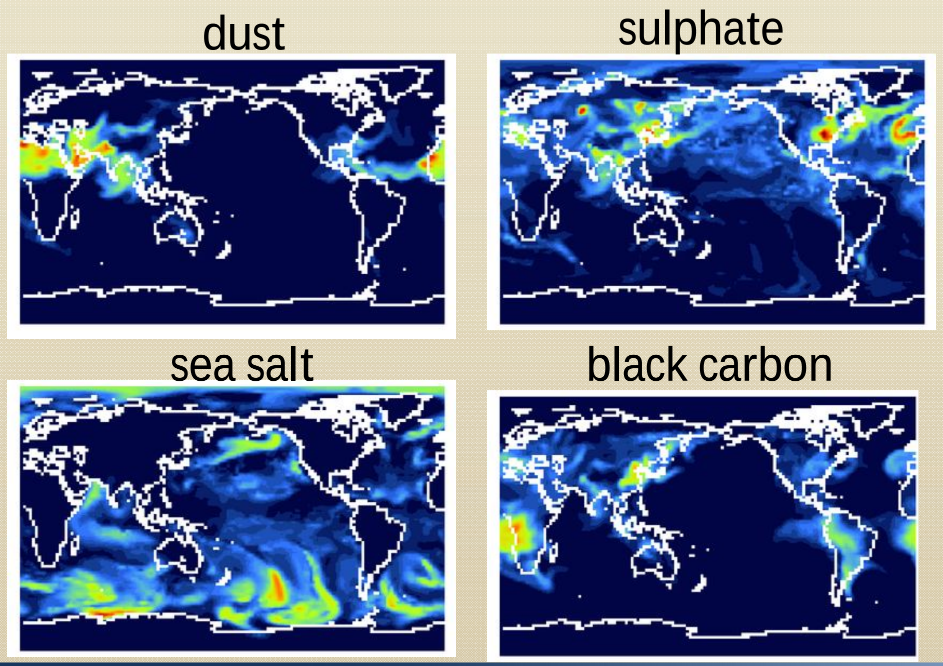
Earth System Pipeline

Goals of our next major model upgrade for climate change projection include:

Simulating the uptake of carbon dioxide by oceans and land

Coupling of tropospheric and stratospheric chemistry into climate model

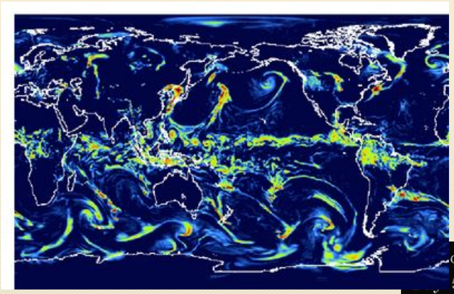
Simulating atmospheric aerosols (particles) and their interactions with clouds

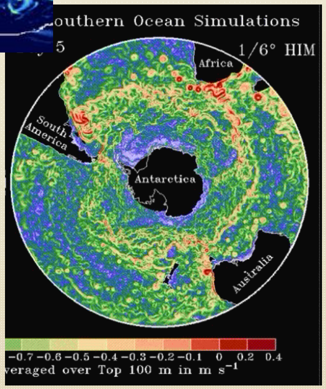


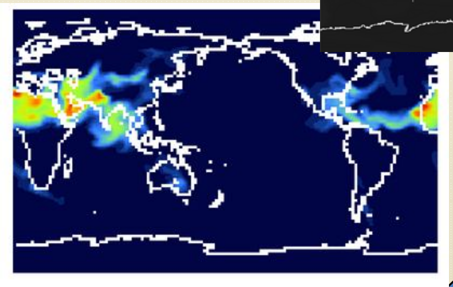
Cooling due to aerosols has balanced part of the warming due to CO_2 in the 20th century

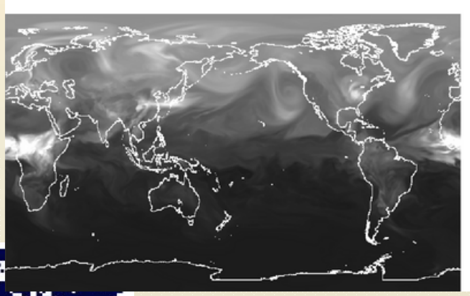
Many air quality⇔ climate connections

NOAA/ GFDL Modeling
What do we have in the pipeline?



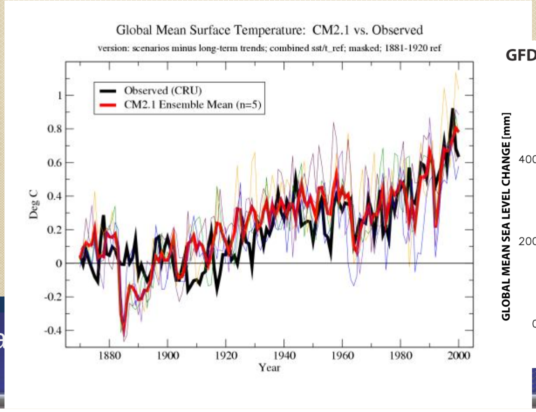


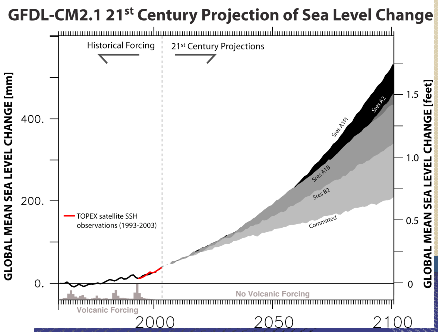




Resolution pipeline

Earth system pipeline





Climate projections

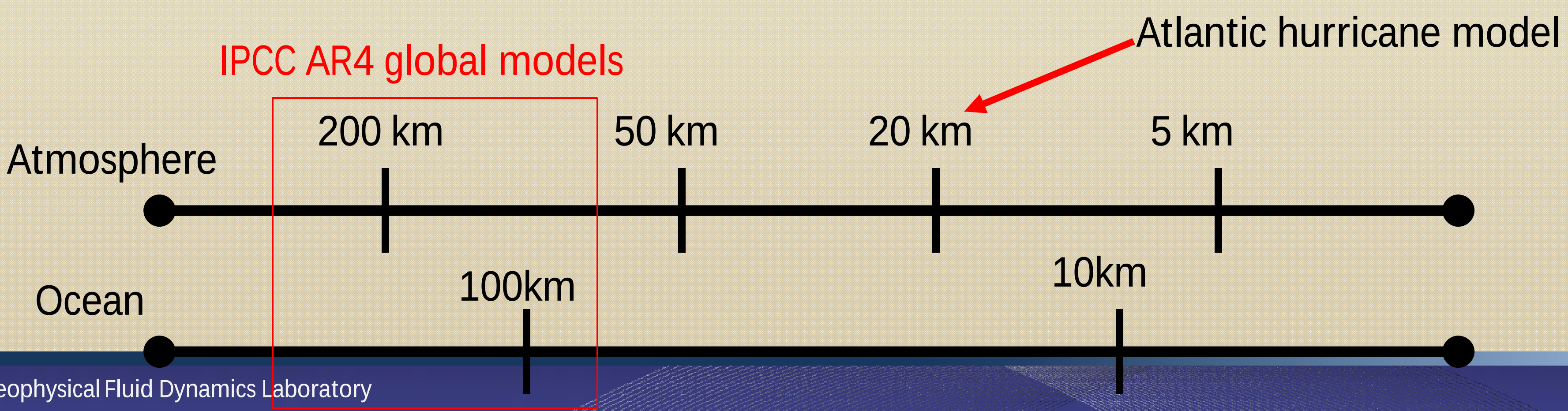
Resolution Pipeline

especially demanding of computational resources

Why is resolution important?

1) *Need to increase the quality of our climate projections on the regional scales that impact economy/society*

2) *Resolving smaller scales improves the entire climate simulation/projection – because small and large scales interact*



NOAA Climate Modeling

Contributions to IPCC AR5 [underway, Report in 2013]

NOAA/GFDL is making advances on 4 streams of modeling activities:

1. **A coupled climate model with more complex physics and interactive atmospheric chemistry (CM3).**
2. **Earth System Models that achieve a closed carbon cycle (ESM2M and ESM2G).**
3. **High resolution ensemble runs for decadal-scale predictions (based on CM2.1).**
4. **Time-slice experiments with high resolution atmospheric models for research into regional climate projections and the impact of small-scale processes on climate (e.g. clouds and water vapor).**

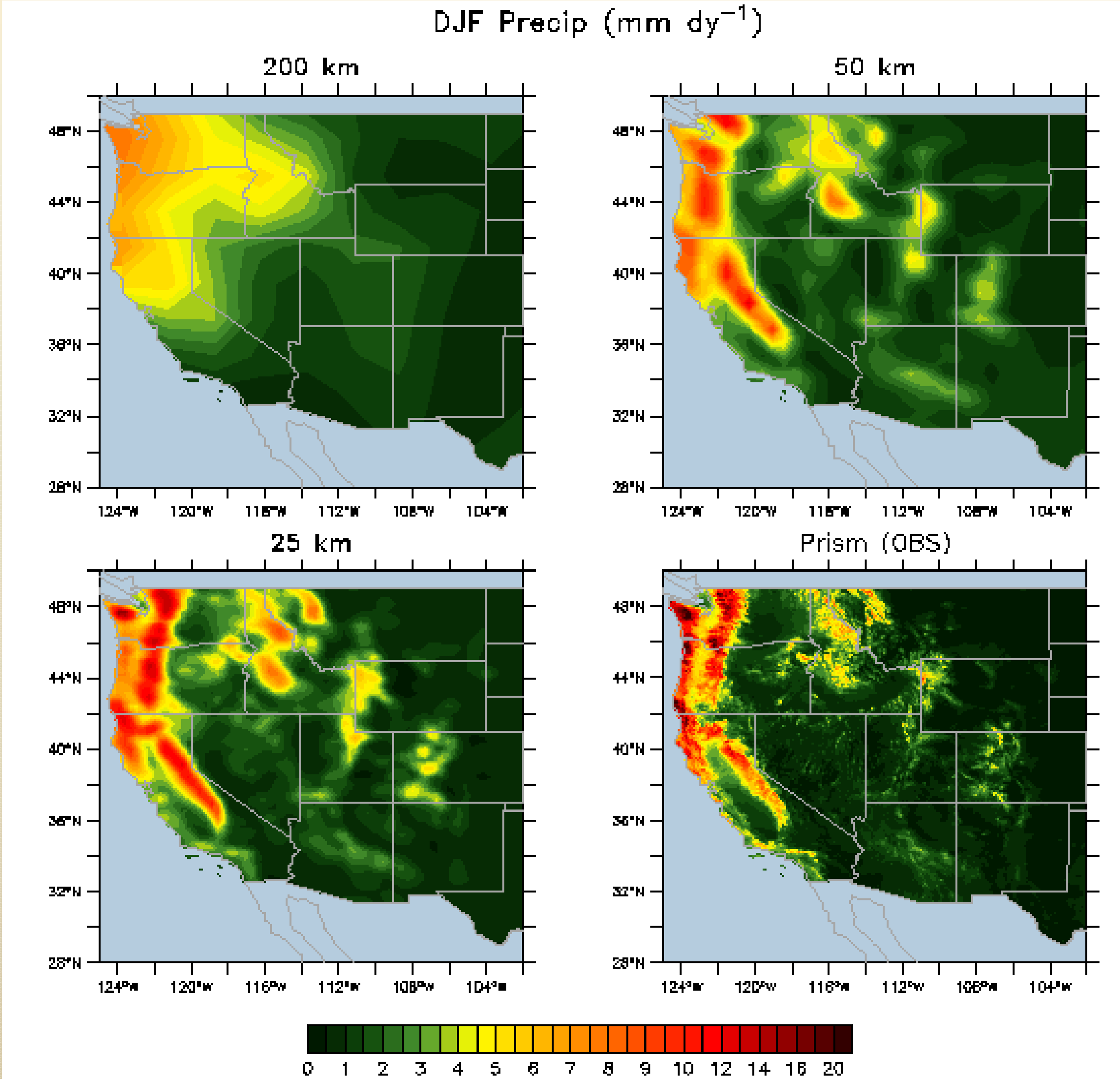
Winter mean precipitation in Western U.S. improves dramatically with horizontal resolution

200 km

50 km

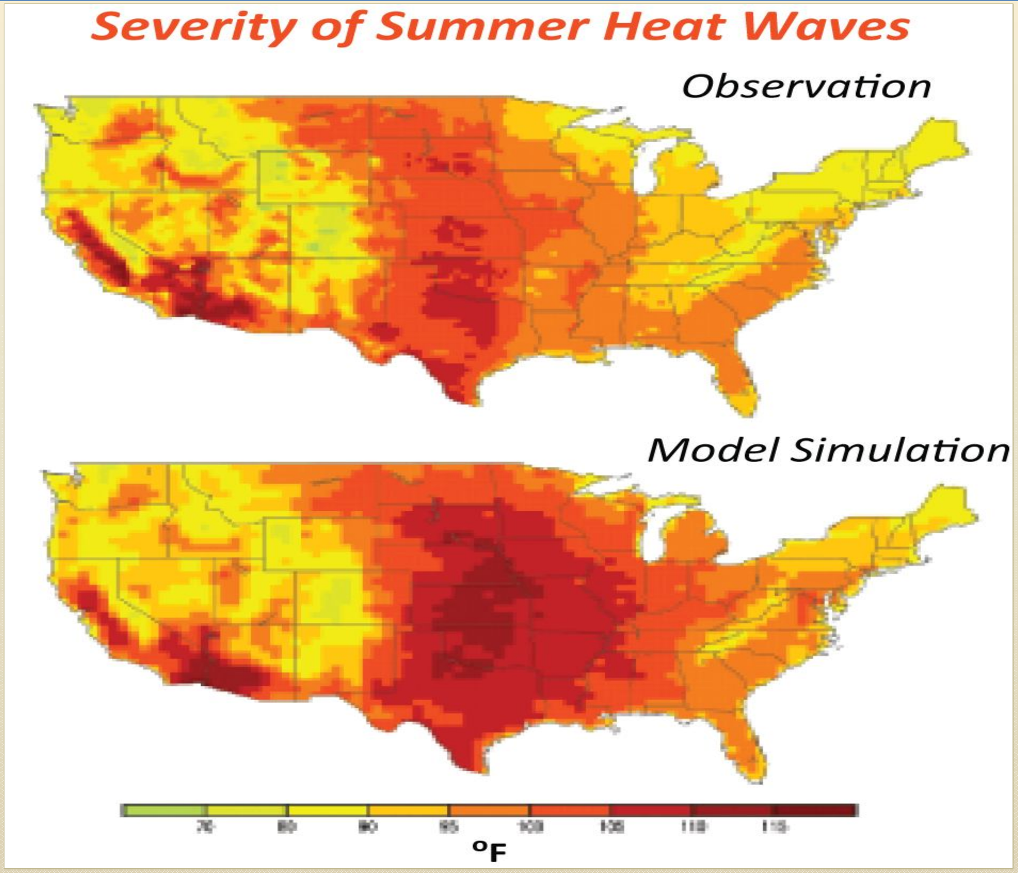
25 km

PRISM observations

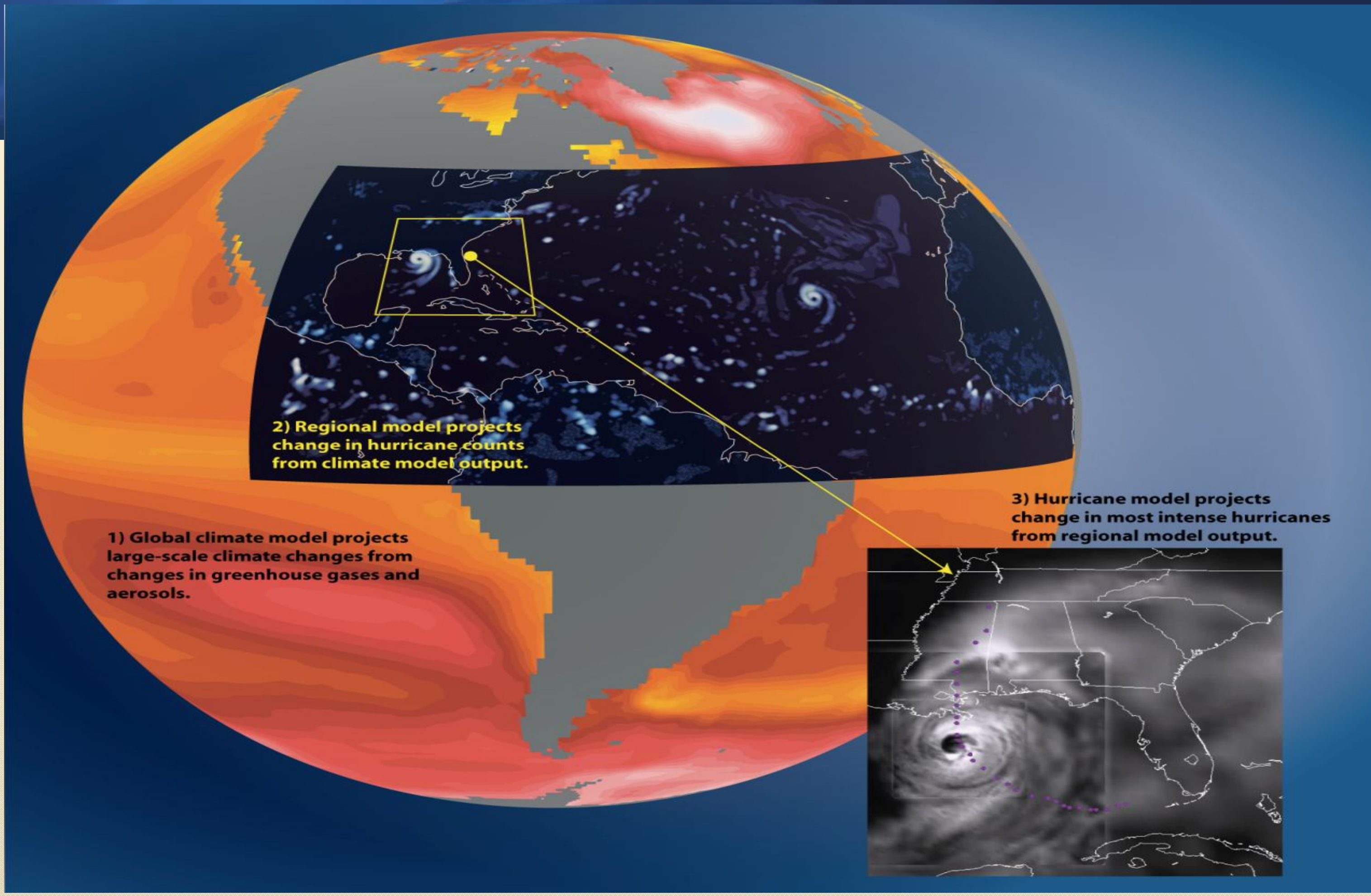


25 year global AMIP simulations

Heat Waves



NOAA/ GFDL high-resolution global model (~50 km) used to simulate the severity and duration of summer heat waves. This model was used to produce the bottom figure, from a 30-year simulation of present-day climate. Top figure is based on observational data for a 24-year period.



Most recent GFDL downscaling study **(Bender et al, Science, 2010)**

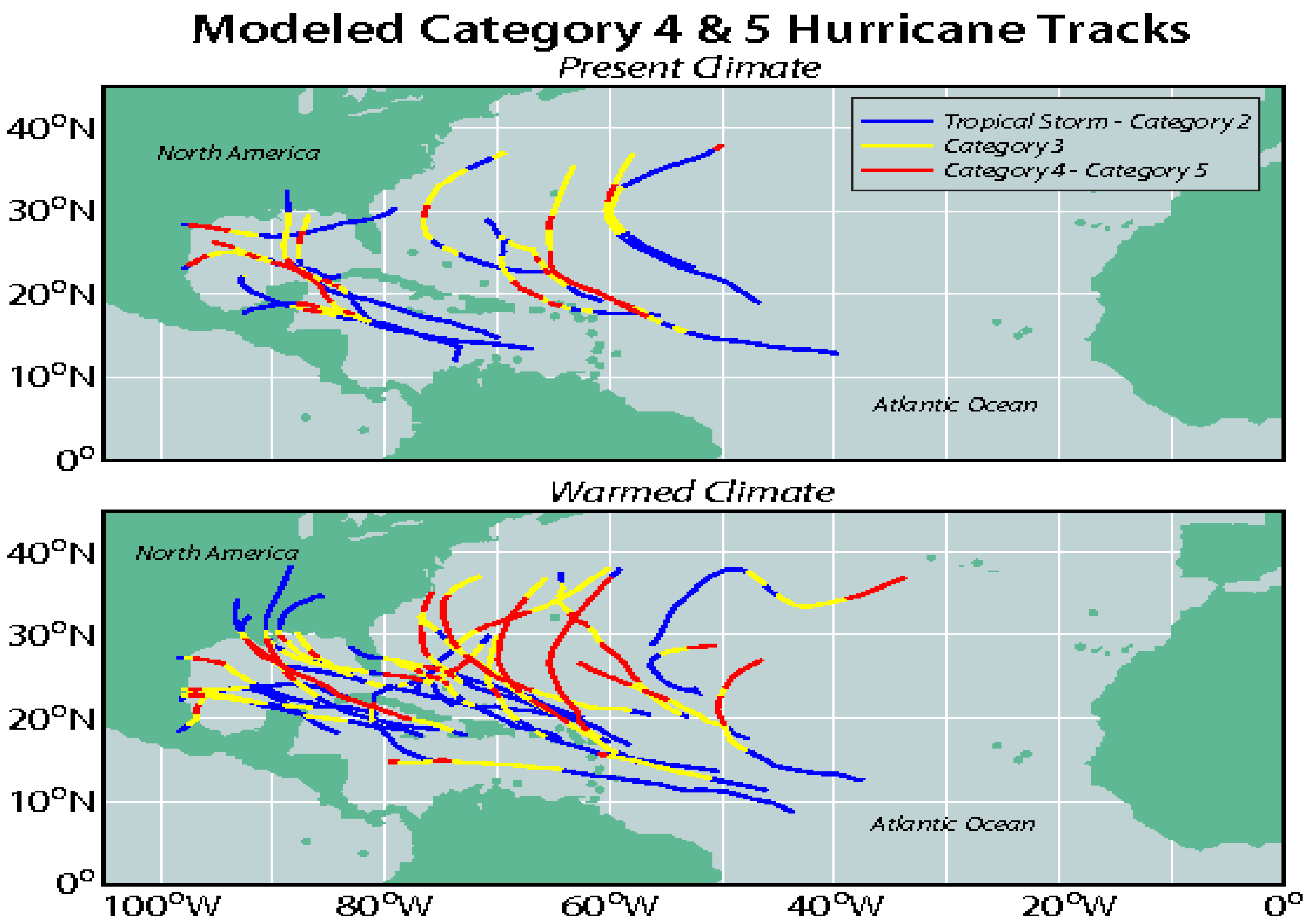
Uses two downscaling steps:

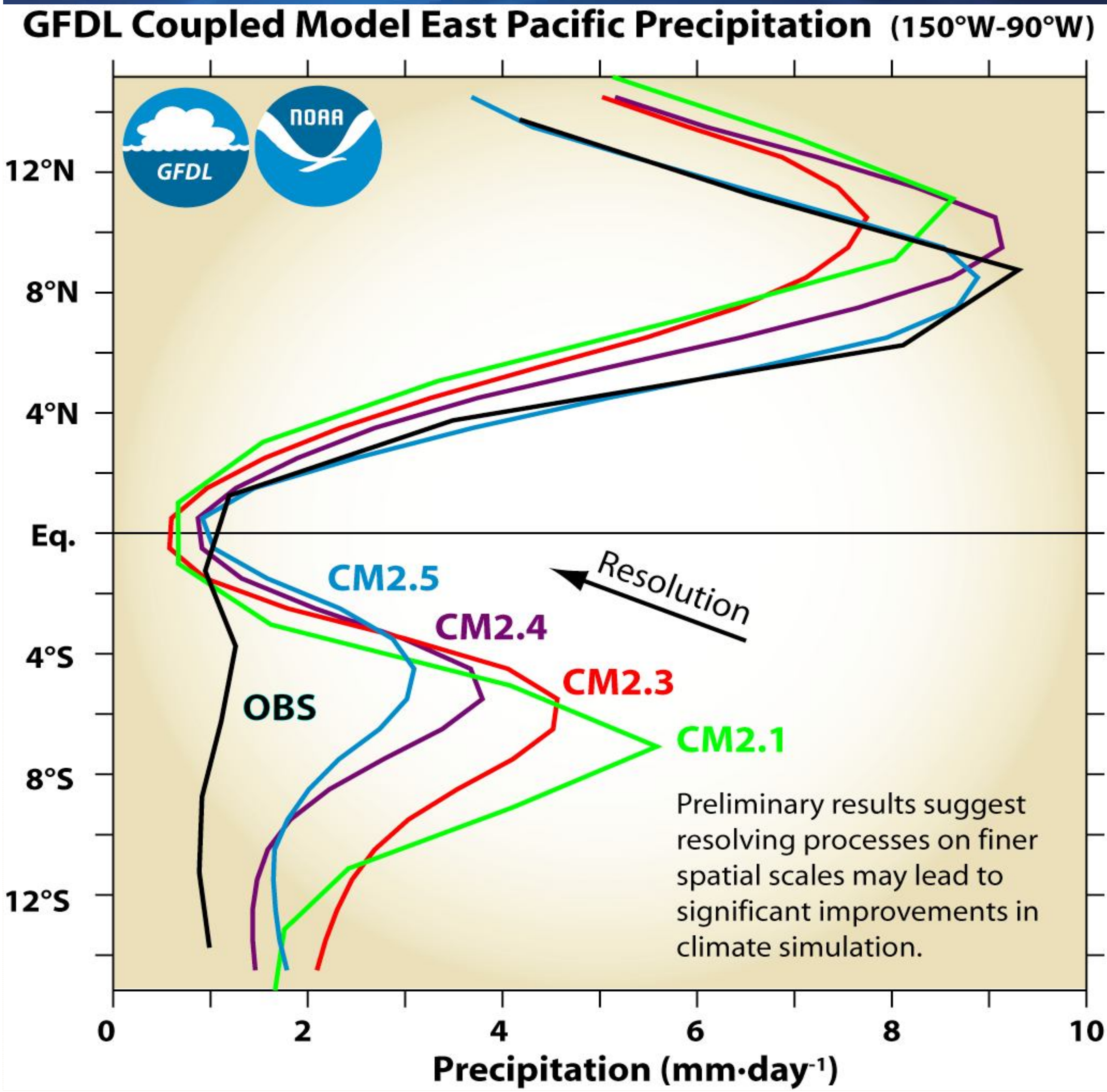
Global CMIP3 models => regional model of Atlantic hurricane season

regional model => operational GFDL hurricane prediction system

Conclusion: Best estimate is for
doubling of cat 4-5 storms in Atlantic by end of century,

Much of the uncertainty arises from global model input





Observed rainfall

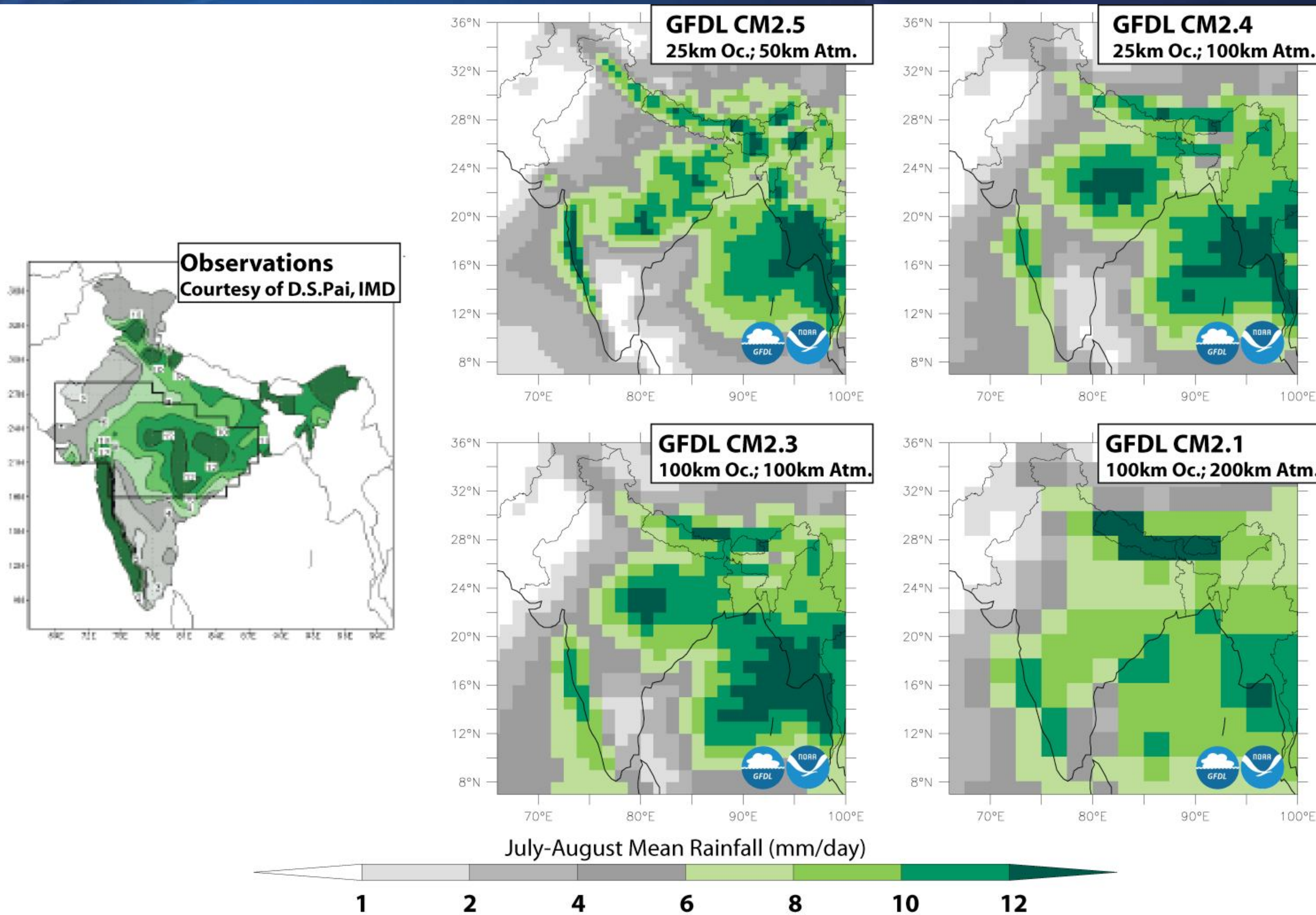
GFDL CM2.1
2° Atmosphere
1° Ocean

GFDL CM2.3
1° Atmosphere
1° Ocean

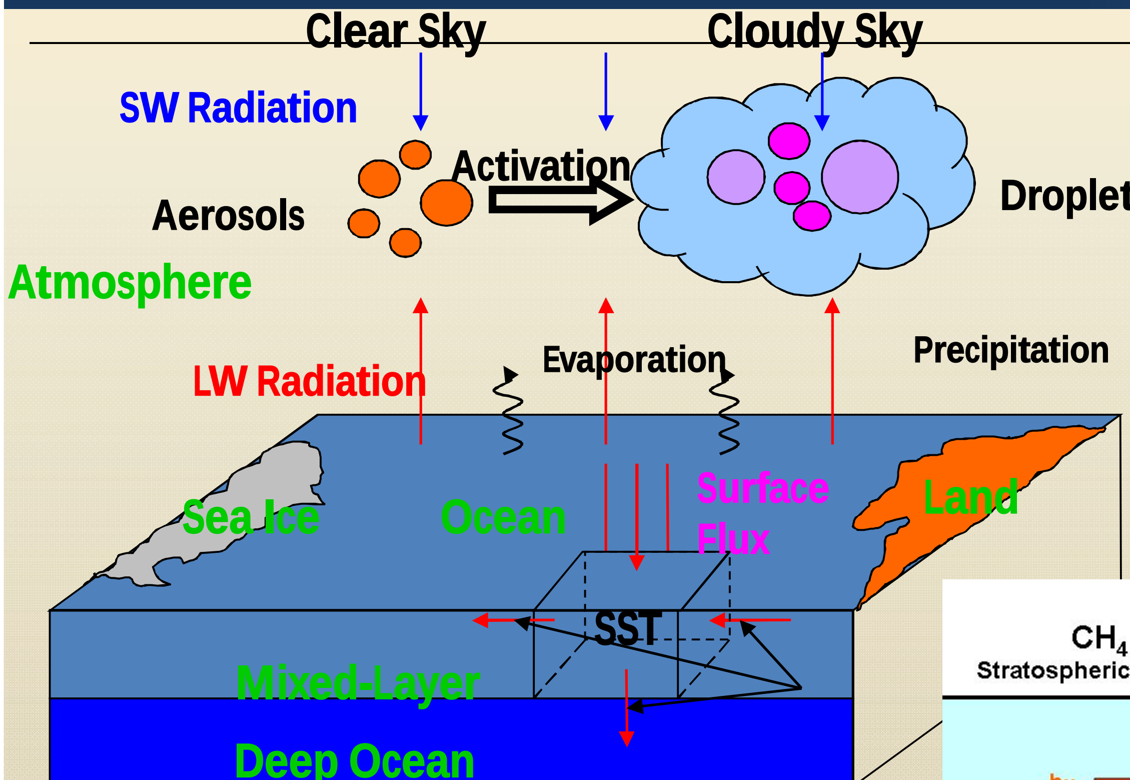
GFDL CM2.4
1° Atmosphere
1/4° Ocean

GFDL CM2.5
1/2° Atmosphere
1/4° Ocean

Enhanced Resolution and Coupling Improve Monsoon Representation

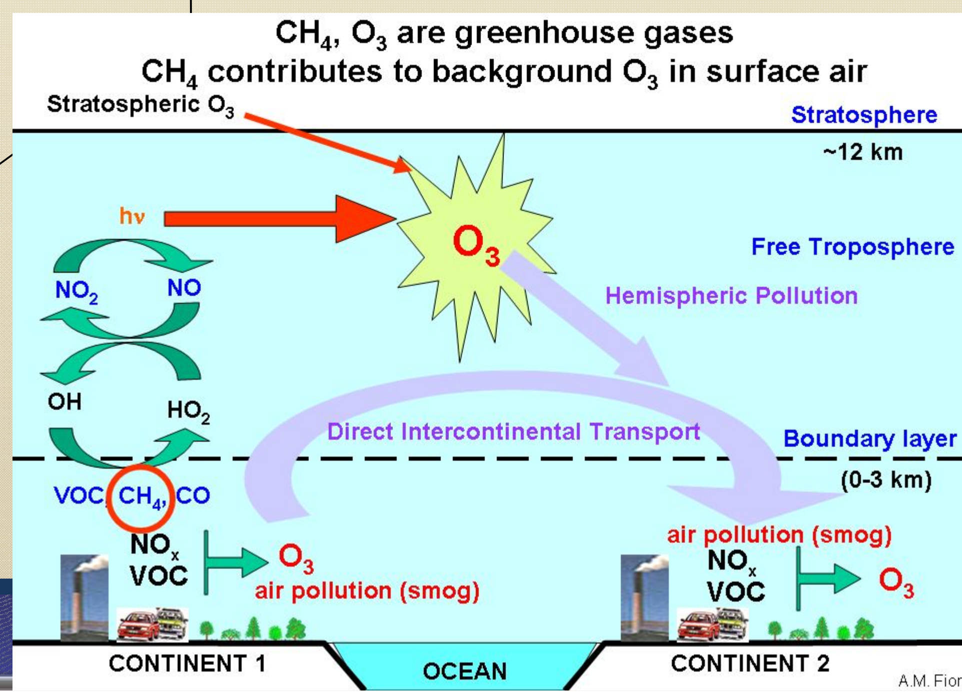


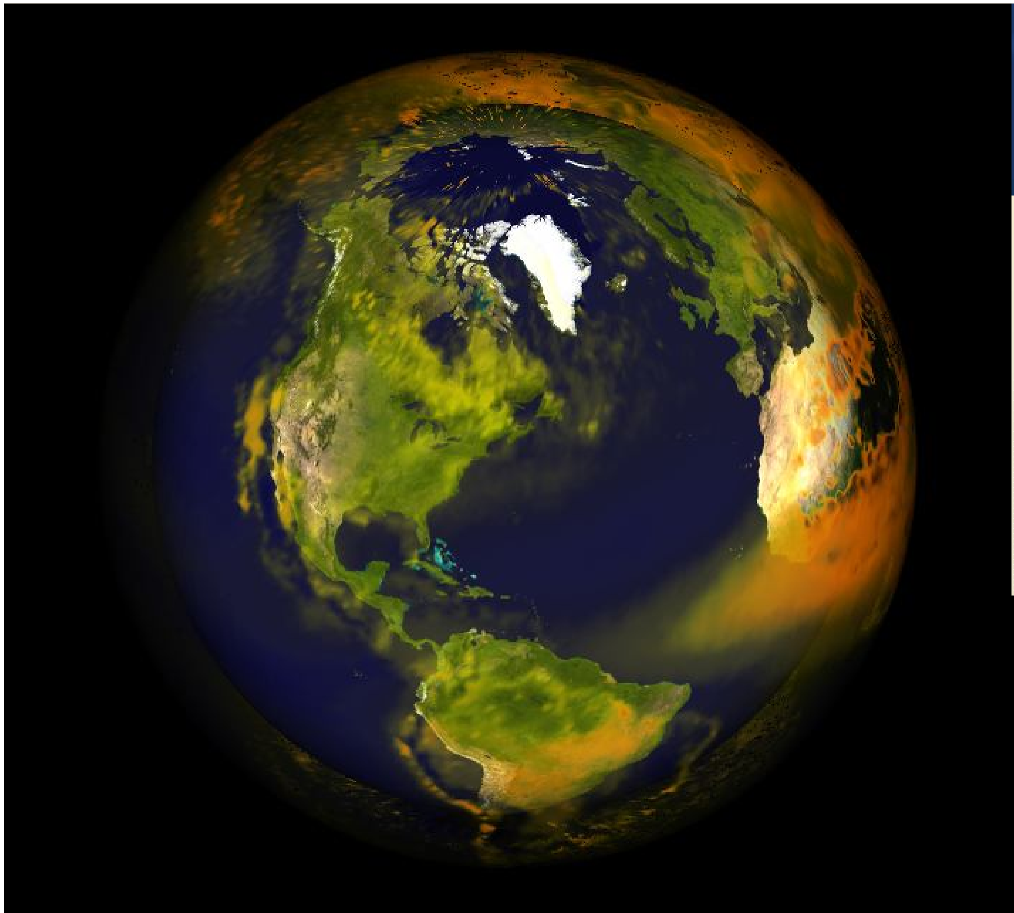
Coupled Chemistry-Aerosol-Climate model



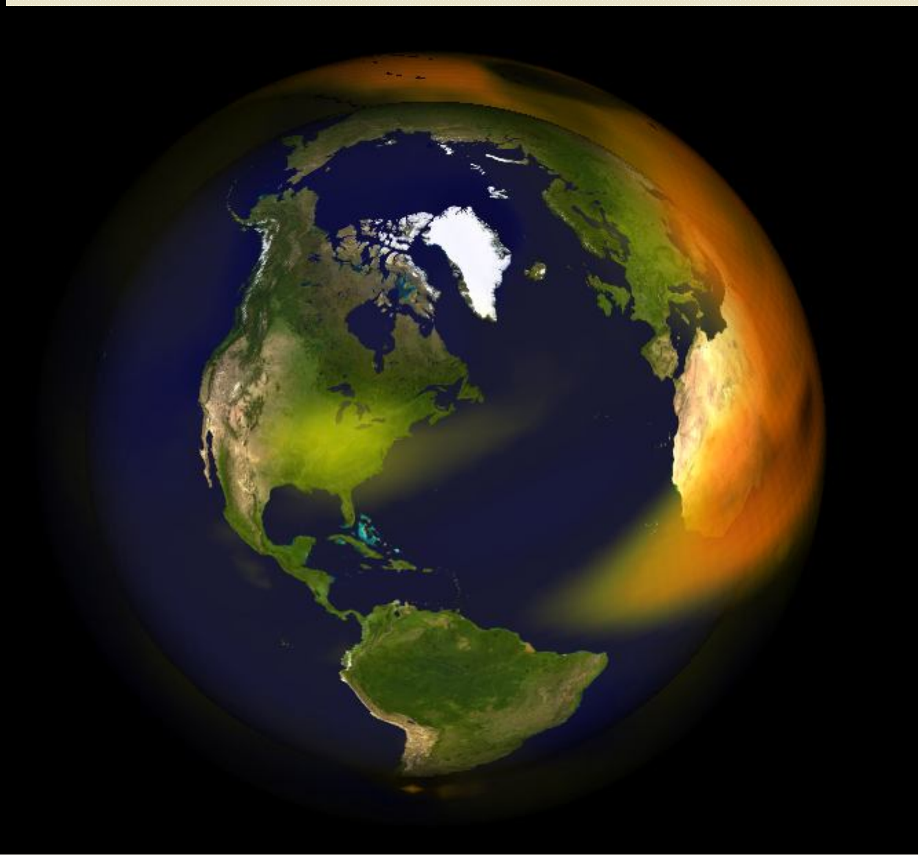
Aerosols and Climate

Global Air Quality and Climate





MODIS (satellite)



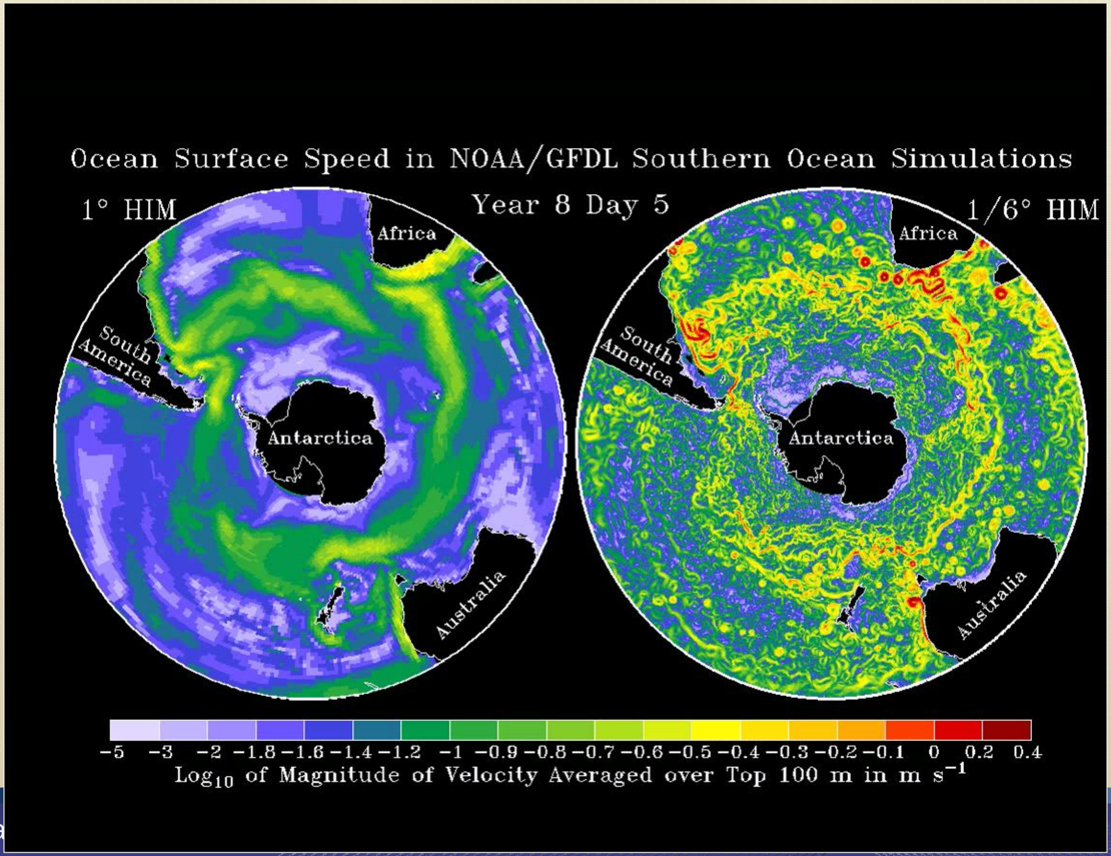
Capturing the global distribution of the short-lived Aerosols spreading out from the source regions

GFDL MODEL

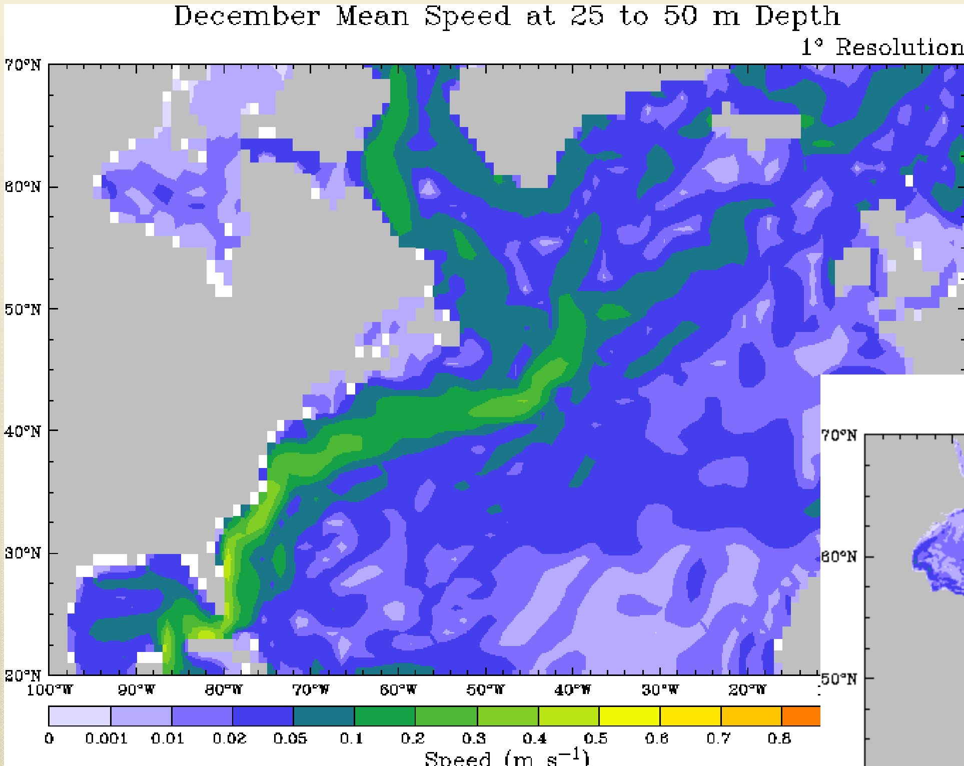
A fundamental breakthrough occurs at scales of 10 km – ocean models become become more realistically turbulent

High resolution simulation of Southern Ocean (GFDL's MESO project).

Small vortices affect oceanic carbon uptake heat, transport of heat towards Antarctic continent, marine ecology of Southern Ocean

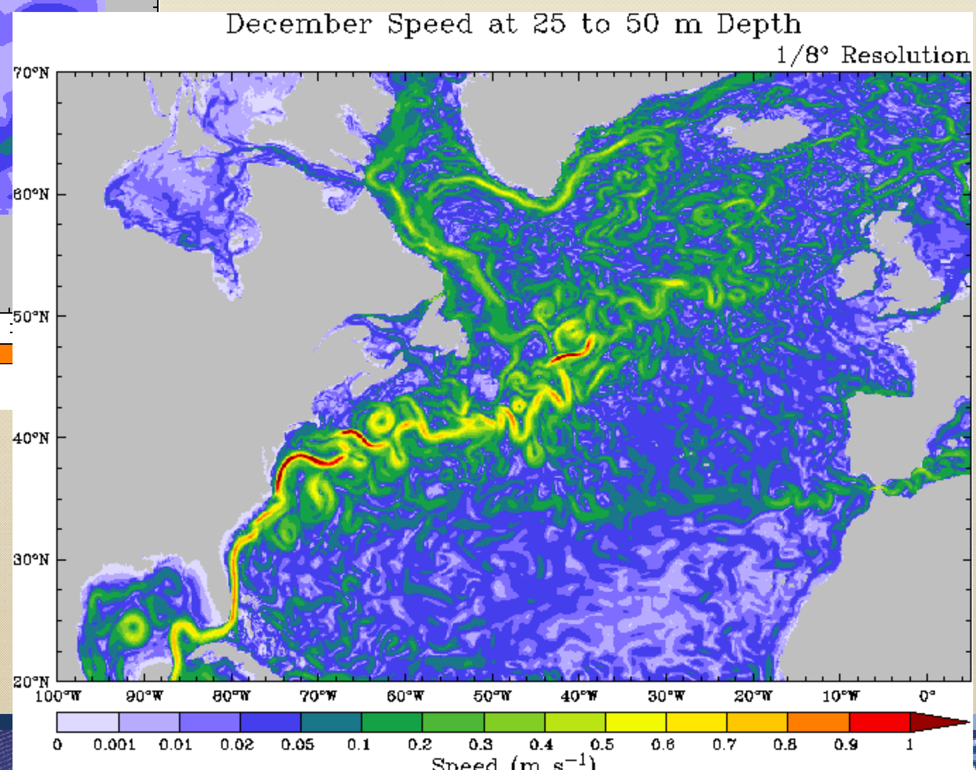


Challenge: Resolution of Coastal-scale Processes

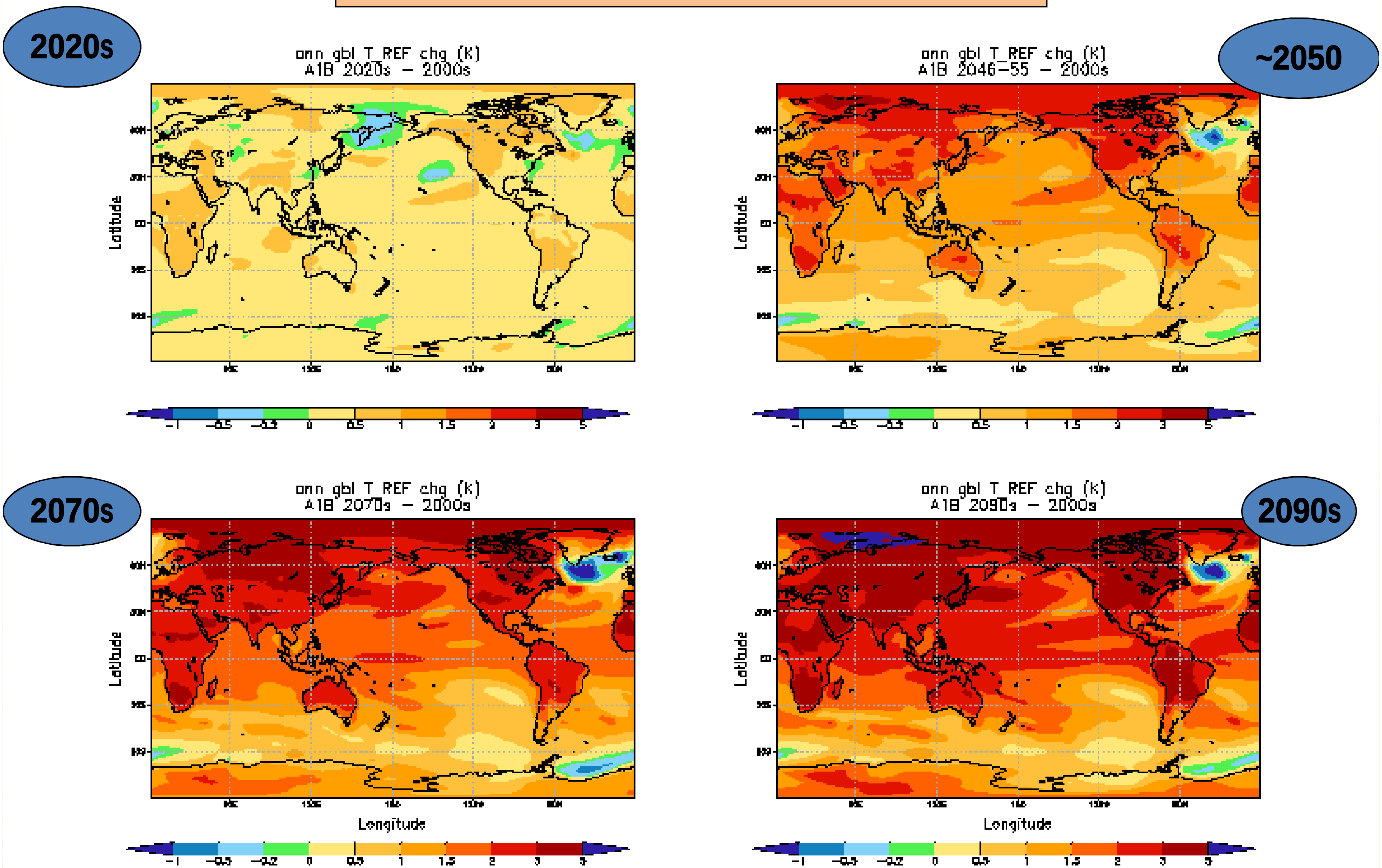


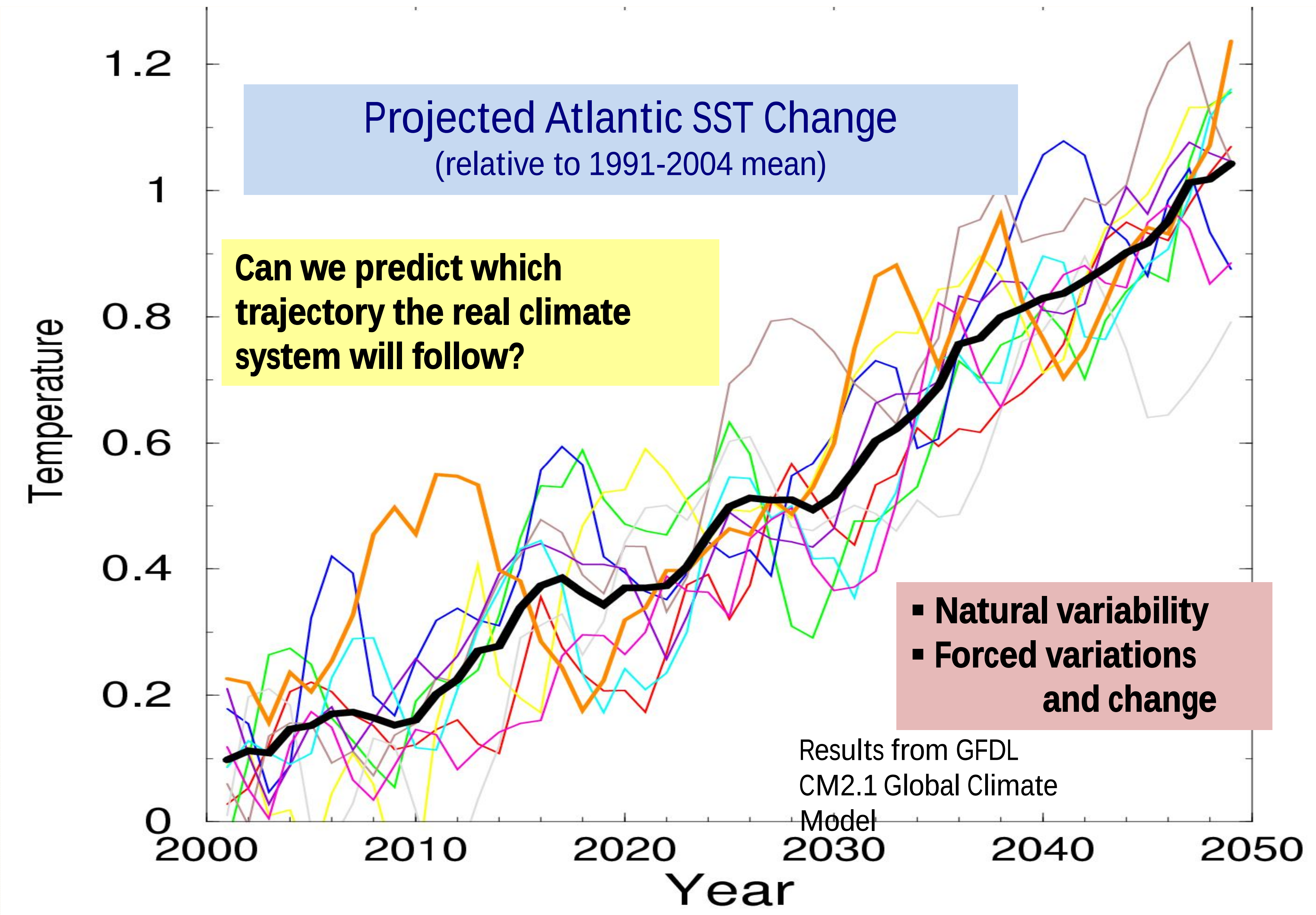
1 deg. Resolution (most AR4 and AR5 climate change simulations)

1/8 degree ocean simulation



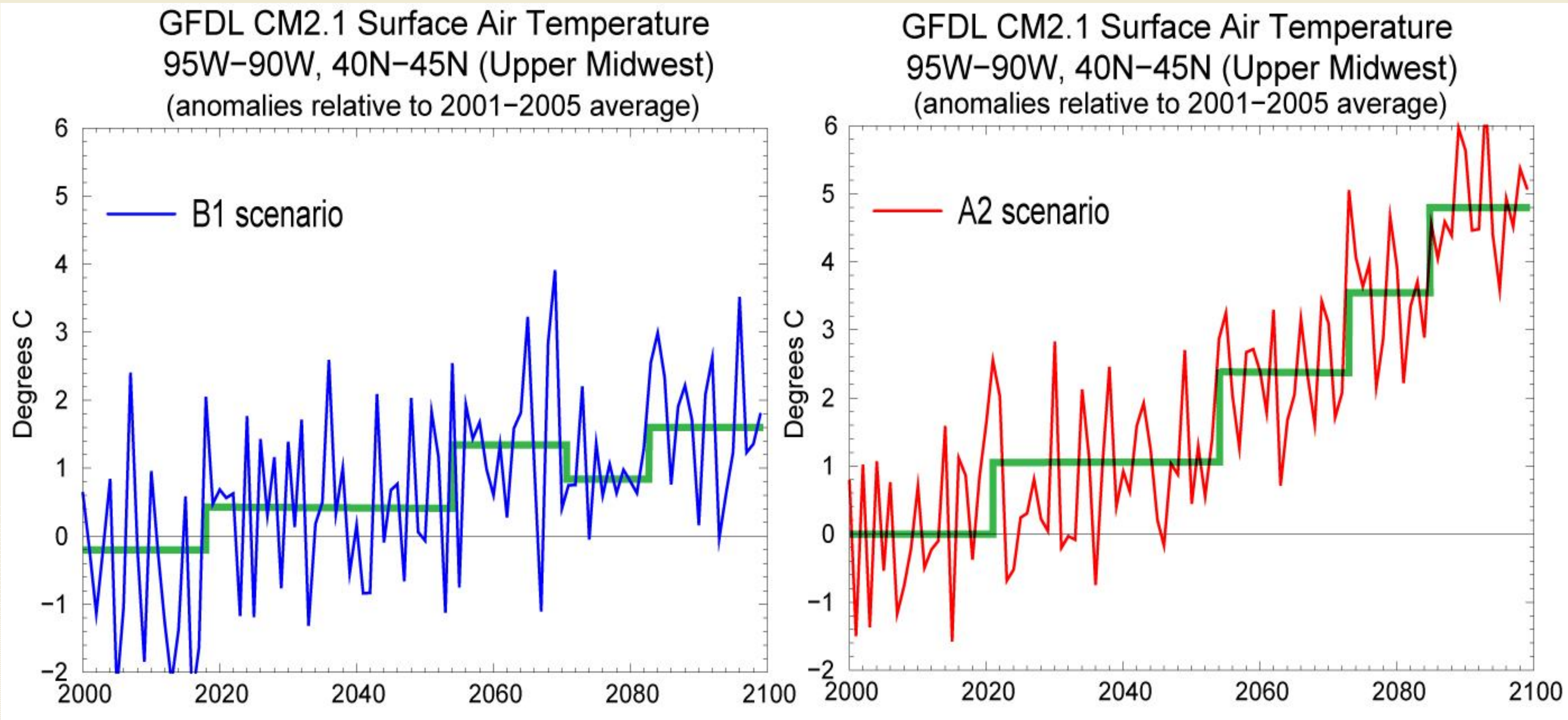
A1B Warming (GFDL CM 2.1)





Projected Atlantic SST Change
(relative to 1991-2004 mean)
Can we predict which trajectory the real climate system will follow?
▪ Natural variability
▪ Forced variations and change
Results from GFDL CM2.1 Global Climate Model
Temperature
1.2
1
0.8
0.6
0.4
0.2
0
2000
2010
2020
2030
2040
2050
Year

Discontinuous Local and Regional Changes



Data Serving – An important part of GFDL plans

- **Node on PCMDI's network (ESG) of data servers for CMIP5**
  - Also provides an independent path to GFDL data
- **Currently serving tens of TB to external users**
  - Potentially hundreds of CMIP5/AR5 TB available
- **Time line**
  - Sept 2013 – WGI public
  - End of 2010 – data available in archive

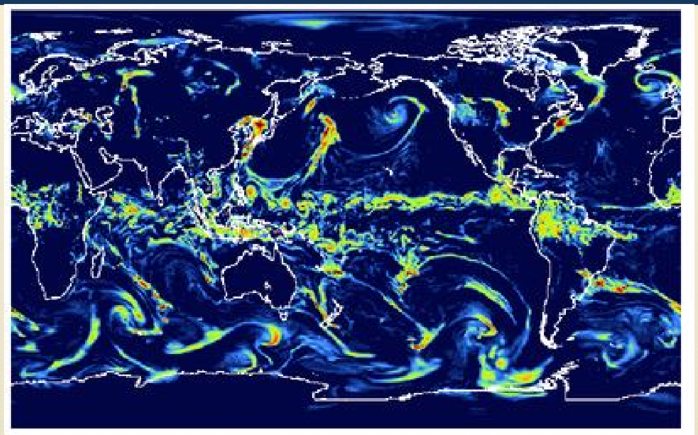
Data processing - Status

- GFDL
  - Huge effort to get data into proper format
  - Whole software system not working yet
  - Need to read and re-write whole of IPCC data set
- External
  - Early tests of network ongoing
  - Data volume a big issue ($$$, infrastructure and software)

The END

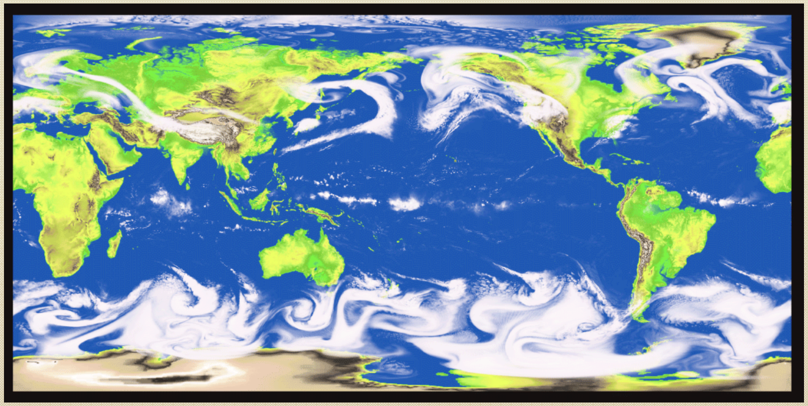
Thank you

Work underway on our next generation atmospheric modeling system suitable for simulations at even finer resolutions



precipitation

A 25 km model – will allow us to model hurricane/typhoons globally
(comparable resolution to the Atlantic simulation that you saw earlier this morning)

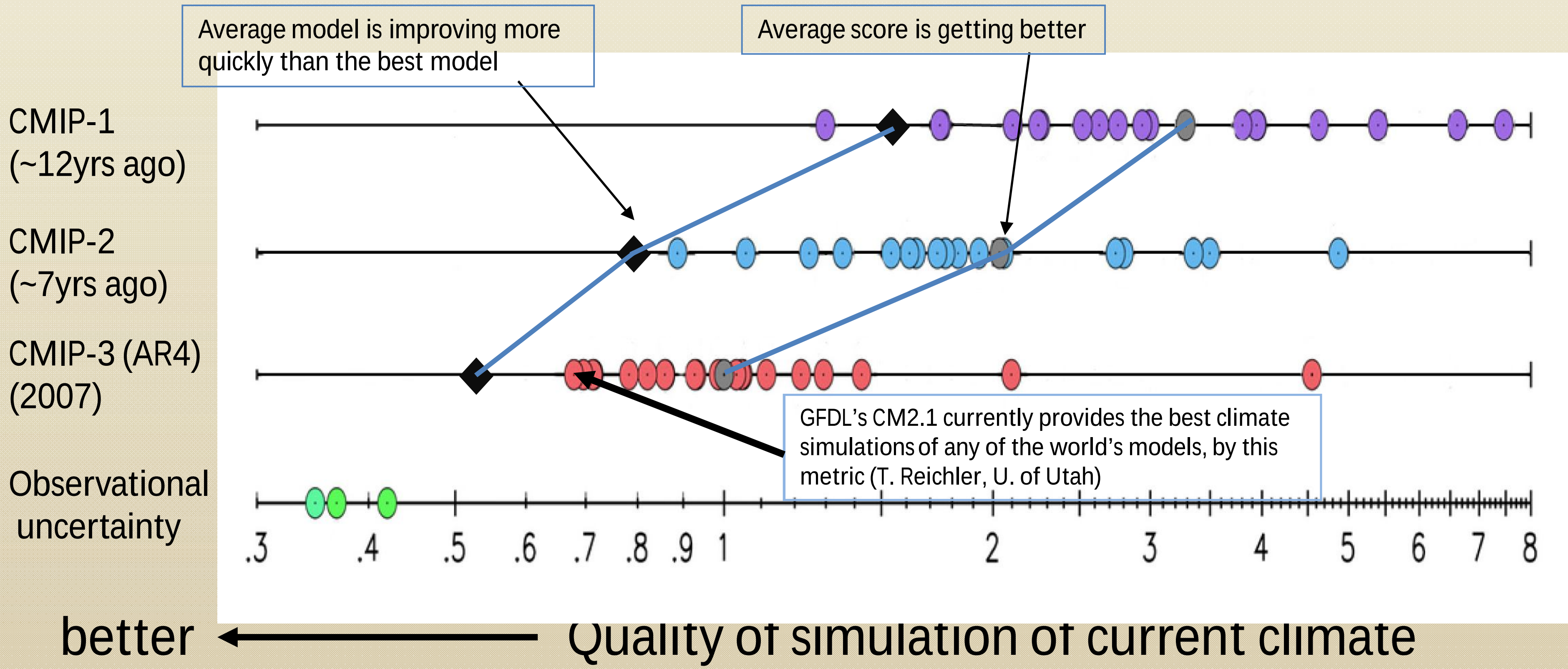


clouds

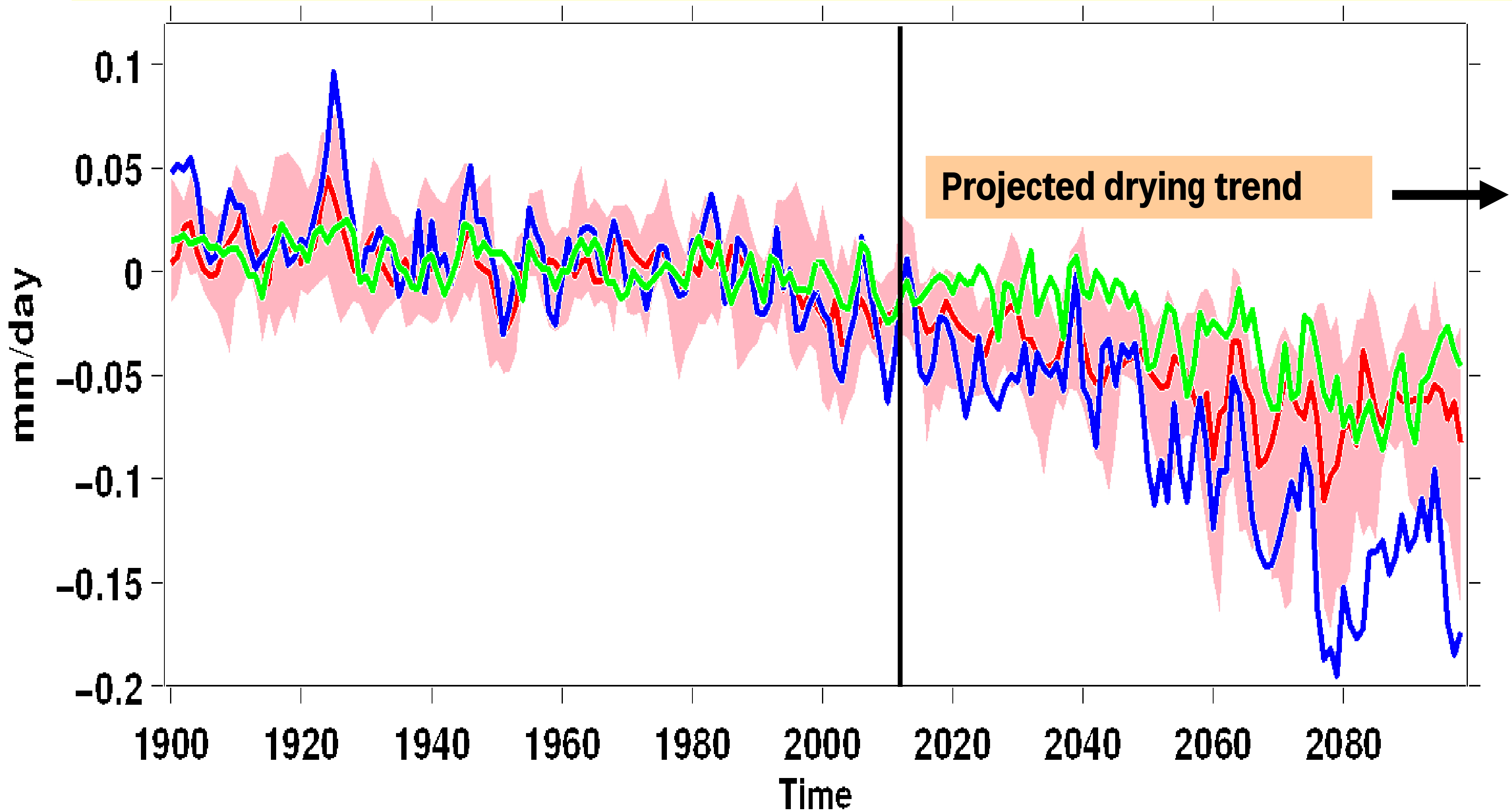
A 5 km model that has the potential to reduce our uncertainty in how the Earth's clouds will respond to global warming

Why an Ensemble of Different Models?

Multiple modeling efforts are needed because information from an ensemble of multiple models is often better than from even the best single model. This was recognized in the USGCRP's (and OSTP-endorsed) Strategic Plan for the Climate Change Science Program, where it was recommended that different approaches to unsolved problems be explored, as well as the IPCC's AR4.



Simulated Change in Southwestern U.S. Water Availability
(precipitation minus evaporation)



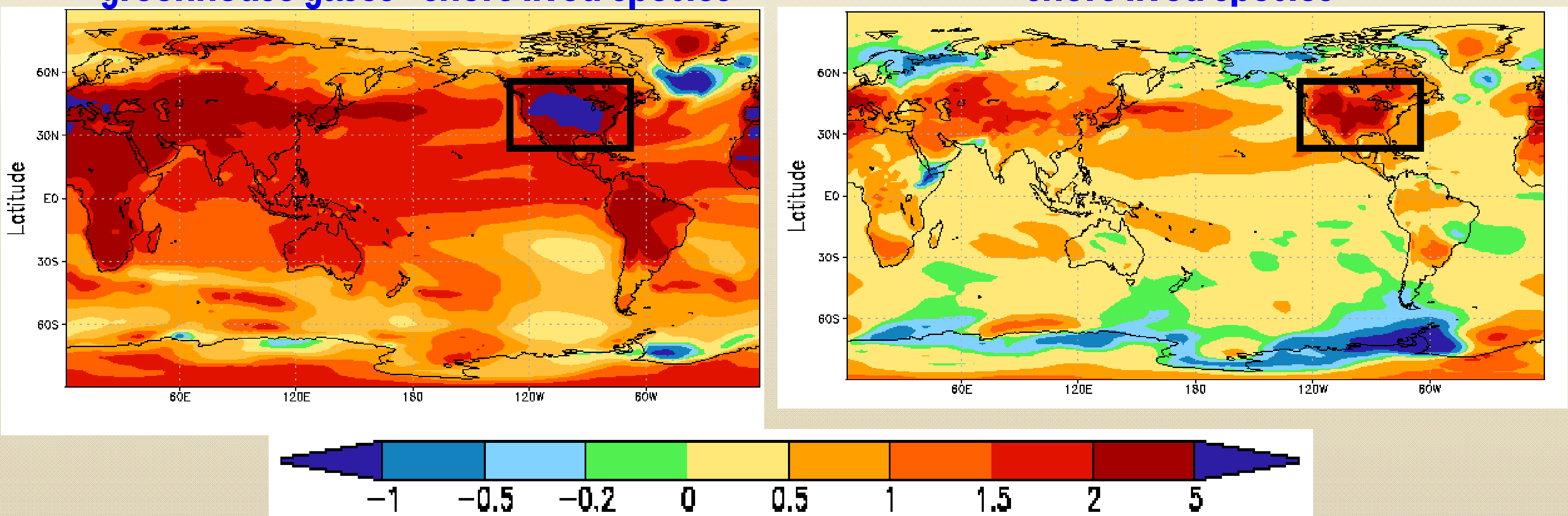
Seager et al., 2007

Up to 40% of U.S. warming in summer (2090s-2000s) from short-lived species

Results from GFDL Climate Model [Levy *et al*., 2008]

From changing well-mixed greenhouse gases +short-lived species

From changing only short-lived species



Change in Summer Temperature 2090s-2000s (°C)

Warming from increases in BC + decreases in sulfate; depends critically on highly uncertain future emission trajectories